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ANATOMICAL AND FIBRE CHARACTERISTICS OF SOME AGRO WASTE MATERIALS FOR PULP AND PAPER MAKING

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ABSTRACT

The present investigations were carried out to see the potential use of stalks of selected species of agro waste materials as an alternative source for pulp and paper making by studying their anatomical characteristics, fibre morphology and their derived indices. Anatomically, fibres were thin walled, rectangular and hexagonal in cross section. The percentage of fibres was greater than other xylem elements and varied from 38% (S. edule) to 46% (C. annum var. accuminatum and S. melongena). The fibre morphology of selected species showed that mean fibre length, fibre diameter, lumen diameter and fibre wall thickness varied from 522.08±61.96µm (G. max) to 1285.80±270.29µm (C. sativus), 18.87±3.56µm (G. max) to 30.16±5.69µm (S. edule), 15.25±3.50µm (C. annum var. accuminatum) to 25.09±5.58µm (S. edule) and 2.52±0.31µm (S. lycopersicum) to 2.81±0.57µm (S. melongena) respectively. The derived indices like Runkel ratio, Slenderness ratio, Flexibility coefficient, Luce's shape factor, Solid factor and Rigidity coefficient of selected species were comparable to Pinus kesiya and Bambusa tulda. The results indicated that though all selected species have potential to be used in pulp and paper making in one way or the other but C. annum var. accuminatum, C. annum var. grossum, C. sativus and S. edule had the most desirable fibre characteristics and their derived indices.

KEYWORDS: Fibre Dimensions, Derived Indices, Pulp and Paper, Anatomical Characteristics, Agro Waste Materials

Original Article

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INTRODUCTION

Pulp and paper industry is one of the largest and highest demand sector in the world of industrial production. The paper products are used not only for writing and printing, but also for other purposes like card board, wrapping etc. The global production of pulp is 192 million tones of which 10.11 million tones are produced by pulp and paper mills of India(Kulkarni, 2013).Though wood is a major lignocellulosic material for production of paper due to its desirable characteristics, but rapid growth of population and industrialization have resulted in huge shortage of this forest resource. Therefore, much attention has been drawn for utilization of non woody plants as an alternate source of fibrous raw materials. The main sources of raw materials are agricultural residue, industrial crops and naturally growing plants. All these materials contain cellulose in their fibres and are considered potential source for pulp with less environmental degradation threat than wood (Ekhaemelo and Tor, 2013).

An examination of literature reveals that agro waste material contributes 22% production of paper (Kulkarni, 2013). Number of studies have been performed to introduce stalks of agro waste materials like *Brassica napus* (Enayati *et al.*, 2009; Housseinpour *et al.*, 2010), *Crambe orienalis*, *C. tartaria* (Tutus *et al.*, 2010),

Hibiscus esculentus and *H. sabdarifa* (Goswami *et al*., 2008) as raw materials for pulp and paper production.

Arunachal Pradesh, one of the biodiversity hot spot areas of the world, is also rich in agriculture sector and about 75% of the population of the state is engaged in agriculture. West Kameng district of Arunachal Pradesh is very popular for cultivation of *S. lycopersicum*, *C. annuum* var. *accuminatum*; *C. annuum* var. *grossum* and *G. max* for local consumption as well as for commercial purposes. The stalks of these crops are left in the field after harvest and are not even used as cattle feed. Though the stalks of seasonal crops are abundantly available in the fields but their fibre characteristics have never been investigated for pulp and paper production. Therefore, the present study is an attempt (a) to study fibre characteristics of selected agro waste materials and (b) to determine their suitability for pulp and paper making with the help of various indices and by comparing with *Bambusa tulda* and *Pinus kesiya* which are commonly used as raw materials for pulp and paper making in North East India.

MATERIALS AND METHODS

The dried stalks of selected agro-waste materials namely *Capsicum annuum var. accuminatum* Fingerh., *Capsicum annuum* var. grossum (L.) Sendt. *Cucumis sativus* L., *Glycine max* (L) Merr. *Sechium edule* (Jacq.) Sw., *Solanum lycopersicum* L., *Solanum melongena* L., were collected from fields during winter season in the month of December, 2014 from different localities of Shergaon, West Kameng district of Arunachal Pradesh. Shergaon lies between the latitude 27^0 06'17.39" North and longitude $92^0$16'19.64" East(Figure 1)

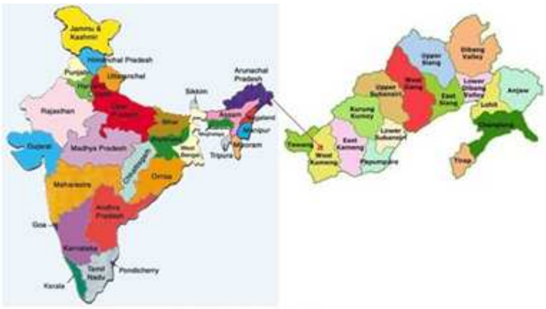

Figure 1: Study Site

Four samples of each selected species were collected randomly. The plants were uprooted and roots were detached. The stem portion of the plants was cleaned, washed with water for 2-3 times and air dried. The present investigation was made on basal parts of the species, therefore3cm long basal portion of each species was kept in FAA solution for 24 hours and then shifted in 50% alcohol for anatomical studies. Basal portion of each sample of all selected species were then cut into small slivers. The samples were macerated with Franklin's solution by keeping them in oven at 60^0C for 24 hours till they become white in colour. The samples were thoroughly washed with water. The test tubes were shaken gently to get fluffy material and were stained with safranine solution. Temporary slides were prepared in 50% glycerol for observation. The cross-section of stalks of selected plant species were cut with the help of sliding microtome and rotary microtome. Sliding microtome was used for cutting hard plant materials while rotary microtome was used for soft plant materials. Permanent slides were prepared by following standard procedures. The fibre dimensions namely fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness were studied with the help of an ocular micrometer fitted in one of the eyepieces of binocular microscope. Fibre length was measured at 40X and the other parameters like fibre diameter, fibre lumen diameter and fibre wall thickness was measured at 400X. Since *Bambusa tulda* and *Pinus kesiya* are commonly used as raw material for pulp and paper, therefore their fibre dimensions were also measured at same

magnification for comparison. The percentage of fibre was determined from the permanent slides at 400X. Various indices like Runkel ratio, flexibility ratio, slenderness ratio, Luce's shape factor, solid factor and rigidity co-efficient (Dutt *et al*., 2004a; Oshima *et al*, 2005) were calculated to see suitability of the selected plant species in pulp and paper making**.** Statistical analysis was carried out with the help of SPSS16.0 software. The photomicrographs of cross-sections of selected plant species at different magnifications and their xylem elements were taken with the help of Leica Image Analysis System attached to Leitz Labrolux research microscope.

RESULTS AND DISCUSSION

Anatomical characteristics are the basis for utilization of lignocellulosic material in pulp and paper making. The anatomical characteristics of stalks of selected agro waste materials are presented in Fig.2.*Cucumissativus*and *Sechium edule* of family Cucurbitaceae are similar in anatomical characteristics. Both have rigid stem with vascular bundles in two layers. Vasicentric tracheids are present in *S. edule*. Metaxylem vessels are very large and surrounded by hexagonal fibres. The other selected species of families Fabaceae(G. *max*) and Solanaceae (*S. lycopersicum, S. melongena and Capsicum* species) have vessels in radial multiples of 2-3, vasicentric parenchyma and 2-4 cells wide rays. Fibres are mostly rectangular (*Solanum lycopersicum*, *S. melongena* and *Glycine max*) and hexagonal in *Capsicum* species in cross section. The fibres of all selected species are long, thin walled and with pointed tips (Fig.2). The results given in Fig.3 show that fibre percentage varies from 38-47% in selected species and is more than *Bambusa tulda* except *Cucumis sativus* and *Sechium edule*. Thus, all selected agro waste materials fulfill one of the provisions to determine their utility for pulp and paper making and is in agreement with the findings of Enayati *et al*., 2009; Sharma *et al*., 2013.

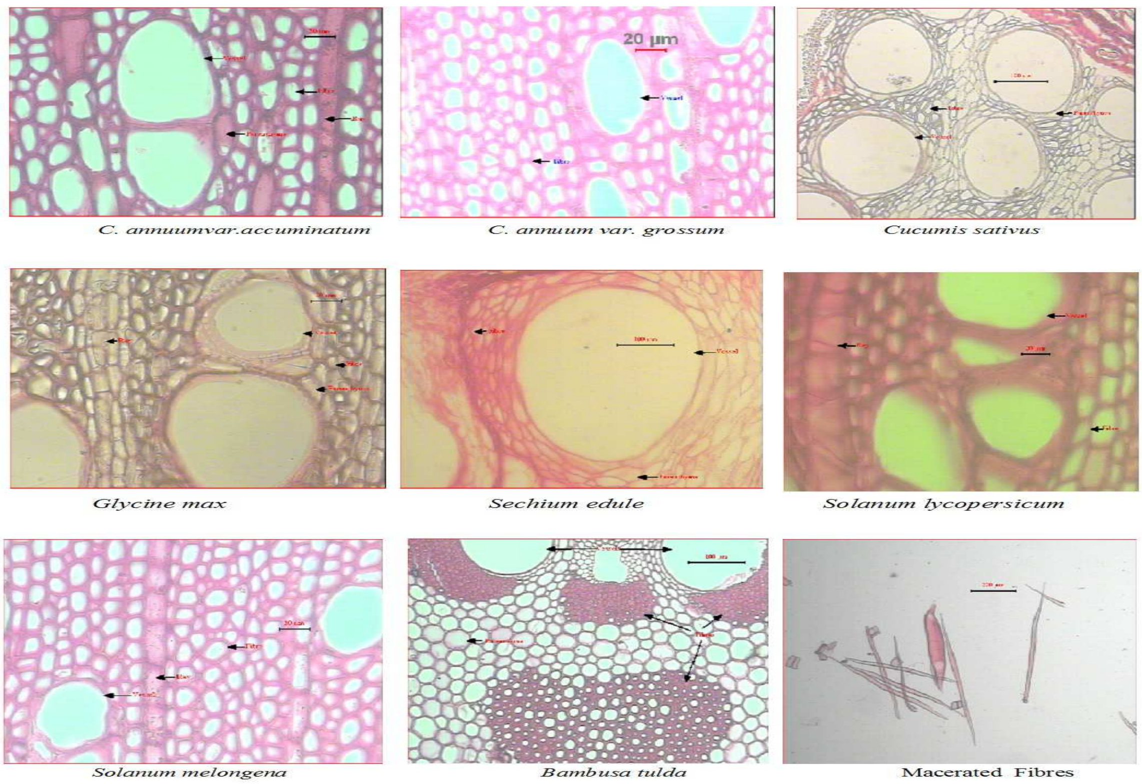

Figure 2: Cross Sections of Stalks of Selected Agro Waste Species and Macerated Fibres

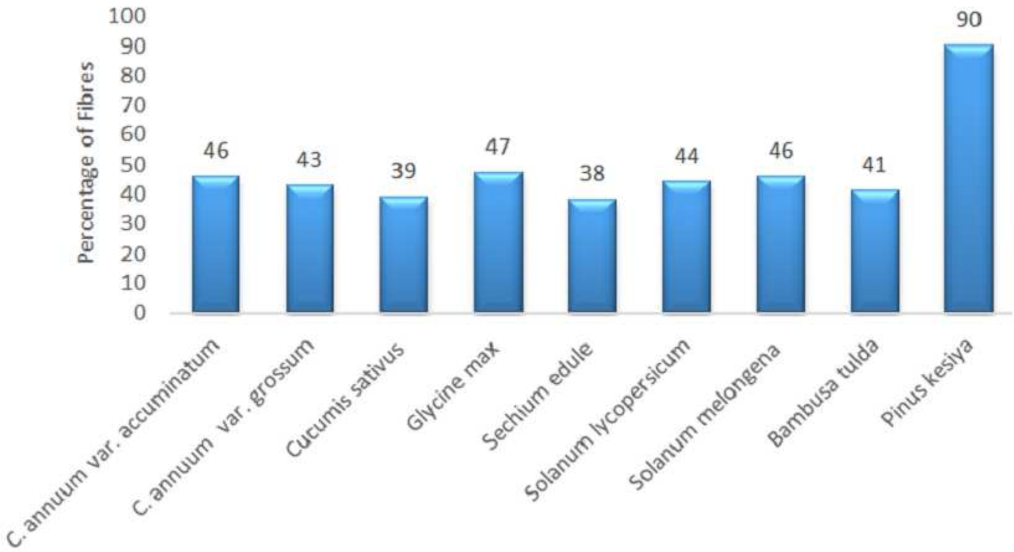

Figure 3: Percentage of Fibres in Selected Species

Fibre characteristics like fibre length, fibre diameter, and fibre lumen diameter and fibre wall thickness play a key role to access the suitability of cellulosic raw materials for pulp and paper. Fibre length influences the tearing resistance of paper. Fibre diameter and fibre wall thickness govern the fibre flexibility and affects the beating of pulp, bursting strength, tensile strength and folding endurance (Wood, 1981; Dutt and Tyagi, 2011). A perusal of literature reveals that hard wood fibres are smaller than softwood fibres and varies from 0.7-1.6 mm in hardwoods and 2.7-4.6mm in softwoods (Ates *et al*., 2008).In the present study, fibre length and fibre diameter vary from 522.08µm to 1285.08 µm and 14.67 µm to 30.61µm respectively. There is not much variation in fibre wall thickness. The fibre length of selected plant species is smaller than *B. tulda* and *P. kesiya* and are comparable to hardwood species except *G. max* (Table 1). The results given in Table 2 show that statistical significant variation exist in fibre length of all selected species except *C. annum var. grossum.* Also significant variation exist in other fibre dimensions like fibre diameter, lumen diameter and fibre wall thickness except *C. annum var. grossum* and *C. sativus*. All the selected species of agro waste materials are thin walled with wide lumen. Hence, from fibre characteristics point of view, the selected species of agro waste materials may be the best source for pulp and paper making.

Table 1: Fibre Dimensions of Selected Species

Plant Name	Fibre length (µm) Range (Mean ±SD)	Fibre diameter (µm) Range (Mean ±SD)	Fibre Lumen Diameter Range (µm) (Mean± SD)	Fibre Wall Thickness (µm) Range (Mean± SD)
Capsicum annuum var. accuminatum	695.56-753.10 (732.25±58.27)	18.81-21.93 (20.65±3.44)	13.26-16.73 (15.25±3.50)	2.60-2.77 (2.70±0.48)
Capsicum annuum var. grossum	718.07-753.10 (740.59±69.60)	21.75-23.49 (22.69±3.55)	16.47-18.29 (17.33±3.45)	2.60-2.73 (2.68±0.35)
Cucumis sativus	1120.90-1485.40 (1285.80±270.29)	23.14-25.39 (24.29±4.713)	17.59-20.19 (18.94±4.66)	2.60-2.77 (2.68±0.39)
Glycine max	496.23-546.27 (522.08±61.96)	17.68-20.80 (18.87±3.56)	12.48-15.51 (13.67±3.478)	2.56-2.64 (2.60±0.34)
Sechium edule	964.10-1065.90 (965.35±156.45)	29.38-31.55 (30.61±5.69)	24.18-25.91 (25.09±5.58)	2.60-2.90 (2.76±0.57)
Solanum lycopersicum	628.84-688.05 (659.28±83.25)	22.10-24.18 (22.97±4.25)	16.99-18.98 (17.92±4.14)	2.34-2.60 (2.52±0.31)

Table 1: Contd.,				
Solanum melongena	646.35-704.73 (669.29±52.13)	20.02-22.79 (21.67±3.49)	14.38-17.33 (16.03±3.41)	2.73-2.86 (2.81±0.57)
Bambusa tulda.	1242.70-1482.90 (1381.00±261.09)	13.52-13.87 (13.65±3.22)	6.07-7.45 (6.76±2.89)	3.21- 3.77 (3.45±0.93)
Pinus kesiya	1736.50-5104.10 (3119.50±808.47)	46.80-83.20 (63.61±11.07)	28.60-72.80 (52.00±12.50)	2.60-7.80 (5.81±1.77)

Table2: Analysis of Variance of Fibre Dimensions of Selected Species

Plant Name	Fibre Length	Fibre Diameter	Fibre Lumen Diameter	Fibre Wall Thickness
Capsicum annuum var. accuminatum	1.52 ^{ns}	1.23 ^{ns}	1.45 ^{ns}	1.04 ^{ns}
Capsicum annuum var. grossum	6.61**	4.80**	5.73**	0.16 ^{ns}
Cucumis sativus	21.25**	1.93 ^{ns}	2.49 ^{ns}	1.09 ^{ns}
Glycine max	3.54*	4.84**	4.66**	0.33 ^{ns}
Sechium edule	7.09**	0.92 ^{ns}	0.56 ^{ns}	1.55 ^{ns}
Solanum lycopersicum	3.26*	1.27 ns	1.26 ns	5.53**
Solanum melongena	9.77**	3.83**	4.39**	0.34 ns

The level of significant used are n. s. =non-significant, * = significant at P≤0.05 level

**= significant at P≤0.01 level

Table 3: Derived Indices of Selected Species

Plant Name	Runkel Ratio	Flexibility Coefficient	Slenderness Ratio	Luce's Shape Factor	Solid Factor	Rigidity Coefficient
Capsicum annuum var. accuminatum	0.38	73.23	36.38	0.30	0.14	0.27
Capsicum annuum var. grossum	0.32	75.95	33.33	0.27	0.16	0.24
Cucumis sativus	0.30	77.17	54.63	0.25	0.30	0.23
Glycine max	0.41	71.66	28.44	0.32	0.09	0.28
Sechium edule	0.23	81.45	32.59	0.20	0.30	0.19
Solanum lycopersicum	0.30	77.37	29.45	0.25	0.14	0.23
Solanum melongena	0.37	73.51	31.59	0.30	0.14	0.26
Bambusa tulda	1.18	48.52	105.27	0.62	0.20	0.51
Pinus kesiya	0.22	81.74	49.04	0.19	4.19	0.18

The important indices like Runkel ratio, Flexibility ratio/coefficient, Slenderness ratio, Luce's shape factor and Rigidity coefficient are derived from the basic data on fibre morphology to determine their suitability for pulp and paper making. Fibres having Runkel ratio less than 1 are considered very good for pulp and paper making because they collapse and provide large surface area for bonding while Runkel ratio more than 1 is considered poor for pulp and paper making as the fibres are stiffer, less flexible and form bulkier paper of low bonded area (Ezeibekwe *et al*., 2009). Also, Singh *et al.* (1991) reported that pulp is of reasonable quality with Runkel ratio of range 0.25-1.5. The selected agro waste materials have Runkel ratio from 0.23 (*S. edule*) to 0.41 (*G. max*). It is very close to Runkel ratio of *P. kesiya* (0.30) but less than *B. tulda* (1.18) (Table 3). The present study is in agreement with the findings of other workers (Goswami *et al*., 2007; Housseinpour *et al*., 2010)

On the basis of flexibility coefficient, Bektas *et al.* (1999) classified the fibres into four categories i.e. (a) The fibres having flexibility coefficient greater than 75 are highly elastic (b) Fibres with flexibility coefficient 50-70 are elastic fibres (c) Fibres with flexibility coefficient between 30-50 are rigid fibres and (d) Fibres with less than 30 flexibility coefficient are very rigid fibres. According to this classification, the flexibility coefficient of selected agro waste materials

varies from 71.66 (*G. max*) to 81.45 (*S. edule*) which show that fibres of all the selected species belong to both elastic and highly elastic categories (Table 3).

Slenderness ratio determines the tearing property of paper. High value of slenderness ratio of fibres provides well bonded and better formed paper (Ashori and Nourbakhsh, 2009). The slenderness ratio of fibrous material more than 33 is considered good for pulp and paper production (Xu *et al*., 2006). The selected species of agro waste materials show that *C. sativus* has maximum slenderness ratio (54.63) and minimum in *G. Max* (28.44). The low slenderness ratio in some of species may be due to presence of short fibres.

Fibre diameter and fibre lumen diameter are important parameters to determine Luce's shape factor and solid factor. These indices are related to paper sheet density. The species with low Luce's shape factor and solid factor values give better strength of paper (Kaur and Dutt, 2013). In the selected species Luce's shape factor and solid factor vary from 0.20 (*S. edule*) to 0.30 (*C. annum* var. *accuminatum* and *S. melongena*) and 0.09 (*G. max*) to0.30 (*C. sativus* and *S. edule*). Luce's shape factor of these species is comparable to *P. kesiya* (0.19) and solid factor is comparable to *B. tulda* (Table 3). The values of both indices are low than other species available in the literature (Goswami *et al*., 2008). Rigidity coefficient determines physical resistance properties of paper. The value of rigidity coefficient is 0.30for *Sesbania aculaeta* (Dutt *et al*., 2004b), 0.35 for wheat straw (Deniz *et al*., 2004), 0.18 for *B. napus* (Housseinpour *et al*., 2010). The present study reveals that value of rigidity coefficient varies from 0.19-0.28 in selected species (Table 3) which is very close to *P. kesiya* (0.18). The present investigation is in agreement with the findings of these workers. Hence, all derived indices show that fibres of selected species of agro waste material may be suitable for pulp and paper making.

CONCLUSIONS

The present investigation shows that fibres are thin walled, rectangular and hexagonal in cross section. The percentage of fibres varies from 38-46% in selected species of agro waste materials. The fibre dimensions and derived indices of selected species are comparable to *P. kesiya* and *B. tulda* which are mainly used for pulp and paper making in NE India. Among selected species *C. annum var. accuminatum*, *C. annum* var. *grossum*, *C. sativus* and *S. edule* have desirable fibre characteristics and derived indices. Hence, these species may be suitable alternative source as raw materials for pulp and paper making.

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